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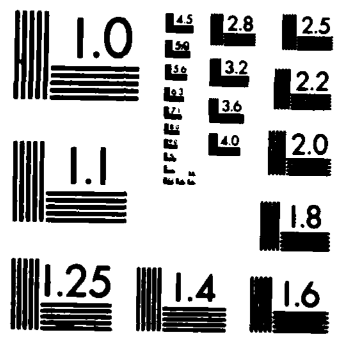
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REPORT NO. T19-86

EVALUATION OF INSULATED MINIATURE THERMISTORS FOR SKIN TEMPERATURE MEASUREMENT IN THE RAT

U S ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

Natick, Massachusetts

AUGUST 1986

UNITED STATES ARMY
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

These experiments were performed to evaluate a miniature thermistor modified by covering its outer surface with insulating foam, as a temperature sensor at three skin sites in the adult male laboratory rat. ~~We modified~~ a high precision thermistor by covering the outer epoxy surface with about ¼ inch ~~of~~ a commercially available insulating foam. Such foam thickness provided sufficient insulation to reduce the influence of ambient temperature on the thermistor reading yet contributed minimal additional probe weight. Results indicate that compared to the insulated thermistor, the uninsulated probe underestimated skin

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temperature measured at the midscapular region of the back, ventral surface of the foot, and dorsal base of the tail at cool ambient temperature (25°C) and overestimated temperature at the back and tail skin sites at high ambient temperature (42°C). The differences in temperature measured by the insulated and uninsulated thermistors were greatest at the back skin site, which was the only fur-covered and the least vascularized area of the rat that we studied. ~~We recommend~~ using an insulated miniature thermistor to reduce the influence of environmental temperature on thermistor readings when measuring skin temperature in a furred laboratory animal is recommended.

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The authors express gratitude to Ms. Susan P. Henry for her technical assistance in preparing the manuscript.

Technical Report 1986

Evaluation of Insulated Miniature Thermistors for Skin Temperature Measurement in the Rat

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ABSTRACT

These experiments were performed to evaluate a miniature thermistor modified by covering its outer surface with insulating foam, as a temperature sensor at three skin sites in the adult male laboratory rat. We modified a high precision thermistor by covering the outer epoxy surface with about 1/4 inch of a commercially available insulating foam. Such foam thickness provided sufficient insulation to reduce the influence of ambient temperature on the thermistor reading yet contributed minimal additional probe weight. Results indicate that compared to the insulated thermistor, the uninsulated probe underestimated skin temperature measured at the midscapular region of the back, ventral surface of the foot, and dorsal base of the tail at cool ambient temperature (25°C) and overestimated temperature at the back and tail skin sites at high ambient temperature (42°C). The differences in temperature measured by the insulated and uninsulated thermistors were greatest at the back skin site, which was the only fur-covered and the least vascularized area of the rat that we studied. We recommend using an insulated miniature thermistor to reduce the influence of environmental temperature on thermistor readings when measuring skin temperature in a furred laboratory animal.

Introduction

Examination of the behavioral and physiological responses of an animal to a change in thermal environment requires knowledge of the skin temperature and surface area available for heat exchange between the animal and its environment. Estimation of mean skin temperature in man (Olesen, 1984) and several animal species (Stitt and Hardy, 1971; Hammel, et al. 1958) consists of measuring surface temperature at 1 to 16 skin sites and then calculating a weighted average temperature using weighting coefficients specific for each skin site (Olesen, 1984). Of particular importance to the determination of mean skin temperature is the accuracy with which temperature measurements can be made and the number and location of skin sites. In addition, computation of heat storage (which reflects the degree of heat dissipation) requires a measure of skin temperature as well as mean body temperature and body surface area (Hammel et al., 1958). Thus, the accuracy of the skin temperature measurement, in turn, determines the accuracy of the heat storage calculation.

Surprisingly, an equation for calculating mean skin temperature and hence, heat storage, has not been developed for the laboratory rat even though the hyperthermic rat is widely used as a research tool for studying the pathophysiology of human heatstroke. The present experiments were designed to evaluate the efficacy of reducing the effect of ambient temperature on thermistor readings at both highly vascularized and furred skin sites in the adult rat hyperthermic model. Future studies will examine the number and location of skin sites required for the best assessment of mean skin temperature in the rat using the results obtained in the present experiments. We modified a fast responding high precision calibrated OMEGA model 427 thermistor by insulating its outer surface with a commercially available

insulating foam (Fomofil). Responses to an increase in environmental temperature were measured in terms of skin temperature at 3 sites on the rat with an insulated thermistor and values were compared to those obtained with a similar uninsulated thermistor.

Methods

a. Modification of the thermistor probe

Skin temperatures were monitored with both insulated and uninsulated rapidly responding high precision calibrated thermistors (Model 427) obtained from OMEGA. The uninsulated probe had an epoxy coating on the side exposed to the environment. The probe was secured in position on each rat using one layer of adhesive tape. The insulated probe was constructed by covering the outer epoxy side of an uninsulated probe with the insulating foam, FOMOFIL. FOMOFIL expands during a 24h curing process, has an R factor of 5 per inch thickness and is extraordinarily lightweight. A 1/4 inch thickness of FOMOFIL foam was used to insulate the "insulated" thermistors.

b. Skin temperature measurements.

Seven adult male rats (Sprague-Dawley) weighing 540 ± 8g were used in this study. All animals were housed individually in an environmental chamber maintained at 26°C, 30% relative humidity and a 12h (0600-1800h) light cycle. Charles River Rat chow and water were provided <u>ad libitum</u>.

Each rat was anesthetized with a minimal dose of sodium pentobarbital (40mg/kg, i.p.), then secured on its ventral surface on a non heat conductive plexiglass grid. A pair of thermistor probes consisting of an uninsulated and a FOMOFIL covered insulated probe was secured at each of three sites: mid-scapular region of back, ventral surface of hindfoot, and dorsal base of tail. These sites were chosen to represent a nonvascular area, a highly vascular

region and an area reknown for its role in thermoregulation, respectively. The hair directly beneath the mid-scapular thermistors was shaven to insure intimate contact between the probe and skin and to minimize the unstirred air boundary layer provided by the hair. The FOMOFIL insulated thermistors were held in position by a strip of Velcro whereas the uninsulated probes were affixed to the animal with a small piece of adhesive attached to the outer surface of the probe.

Rectal temperature was measured with a small animal thermistor (YSI, 401) inserted 6.5 cm beyond the anal sphincter and a Cole-Palmer thermometer (Model 8110-20). Ambient temperature was monitored (YSI, 700) with a Cole-Palmer telethermometer (Model 5810).

Following completion of thermistor placement, an arbitrary time zero was set. Each rat was kept in a room at $25 \pm 1^{\circ}C$ for 20 min (COOL CONTROL). After this control period, each animal was heated in an environmental chamber set at $42 \pm 0.5^{\circ}C$ (HEAT) until the animals' rectal temperature reached $41-42^{\circ}C$. Each animal was then returned to $25^{\circ}C$ and monitored for an additional 30 min (COOL RECOVERY). Skin and rectal temperatures were measured at 5 min intervals.

Statistical analyses were performed using the Student's t-test and significance was accepted at $p \leq .05$ level.

Results

During the first 20 min at $25^{\circ}C$ ambient (COOL CONTROL), the temperature readings obtained with the insulated probes were significantly higher than those obtained with the uninsulated probes at the back and tail skin sites (Figures 1a, 1b, and 1c). These significant differences in temperature between the insulated and uninsulated thermistors (Figures 2a, 2b, and 2c) ranged from -0.05° to $1.2^{\circ}C$ at the midscapular region of the back ($p < .01$) and from 0.9° to $1.7^{\circ}C$ at the dorsal aspect of the tail ($p < .0001$).

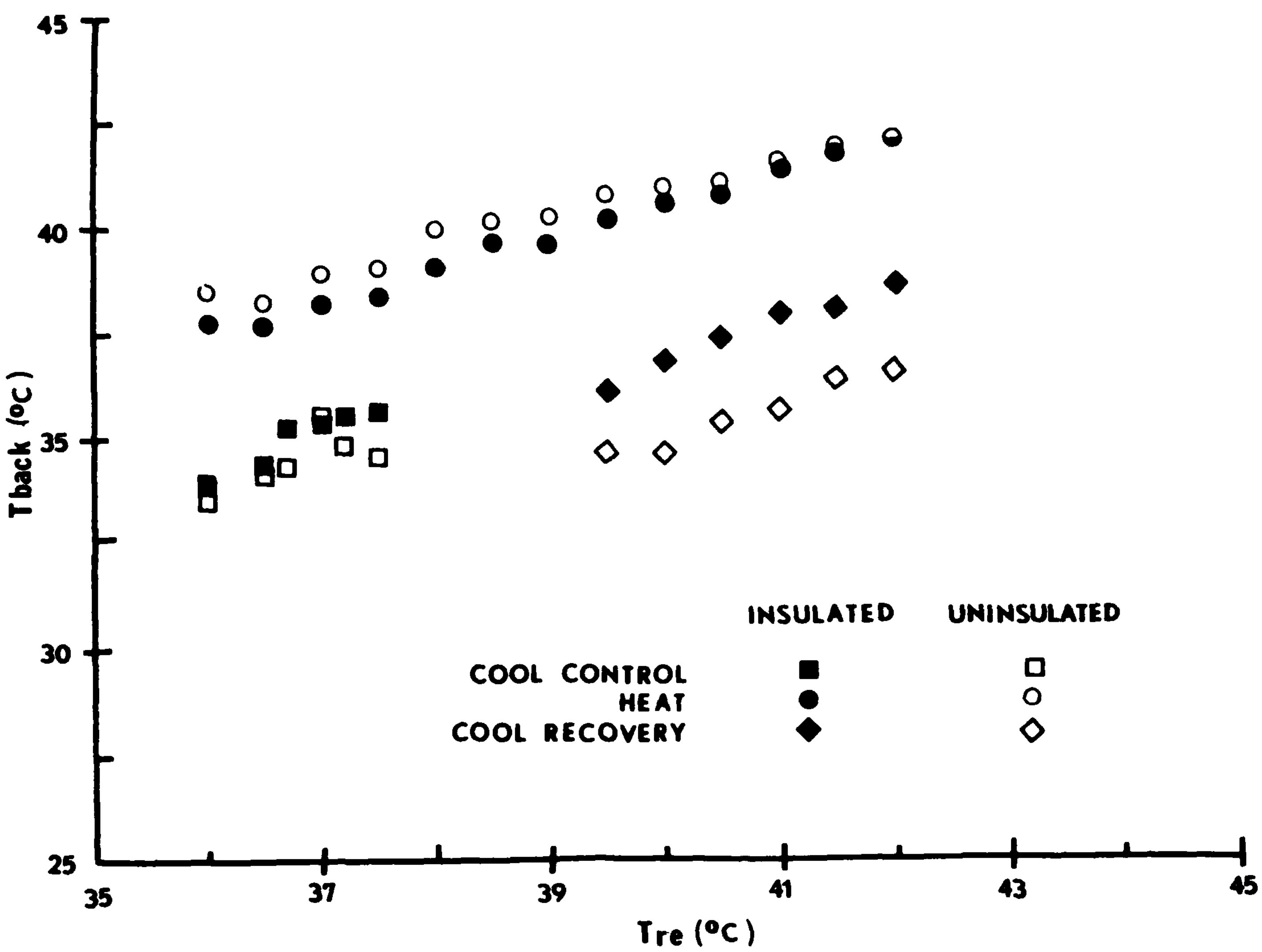

Figure 1a. Skin temperature measured at the back plotted against rectal temperature during COOL CONTROL, HEAT and COOL RECOVERY.

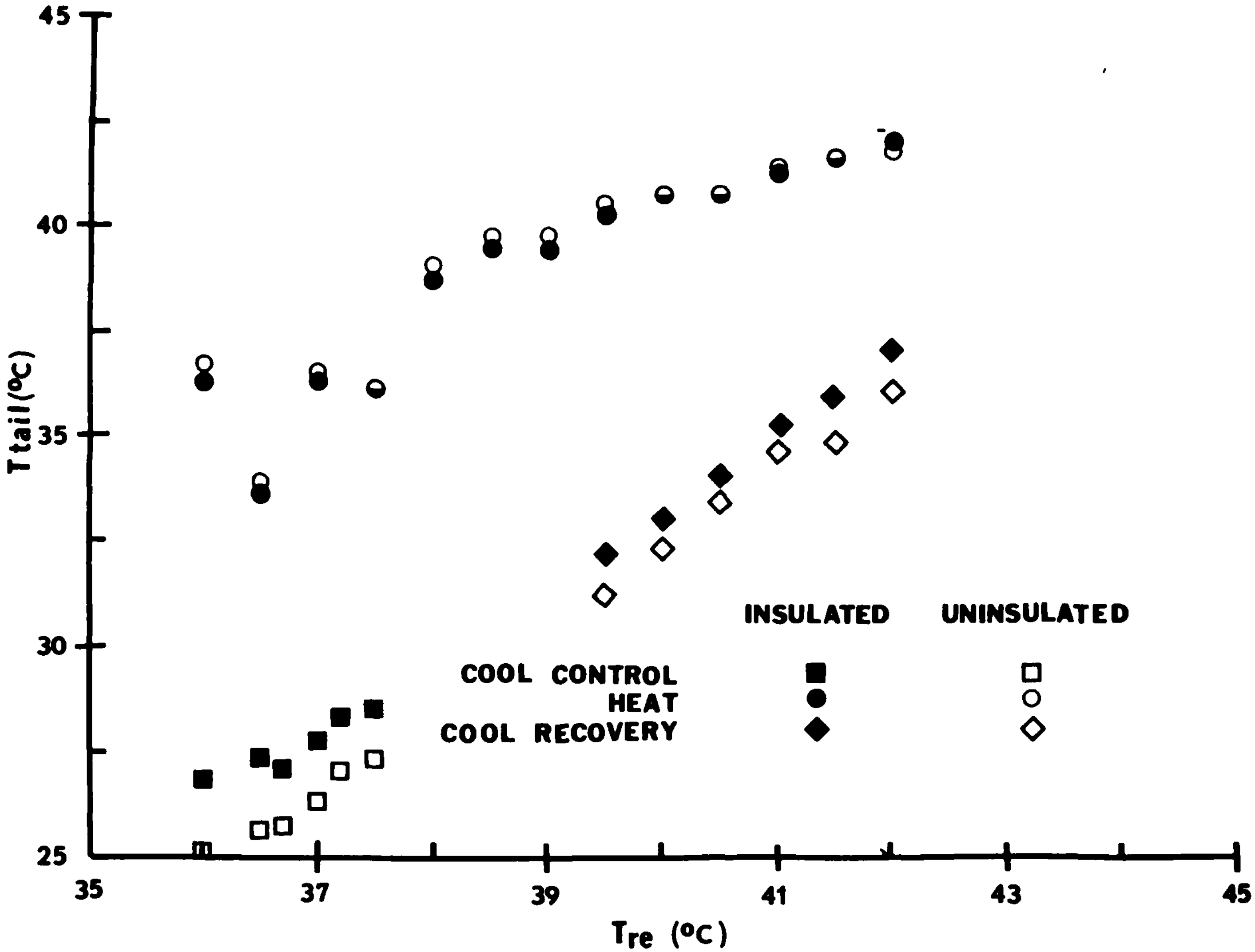

Figure 1b. Skin temperature measured at the tail plotted against rectal temperature during COOL CONTROL, HEAT and COOL RECOVERY.

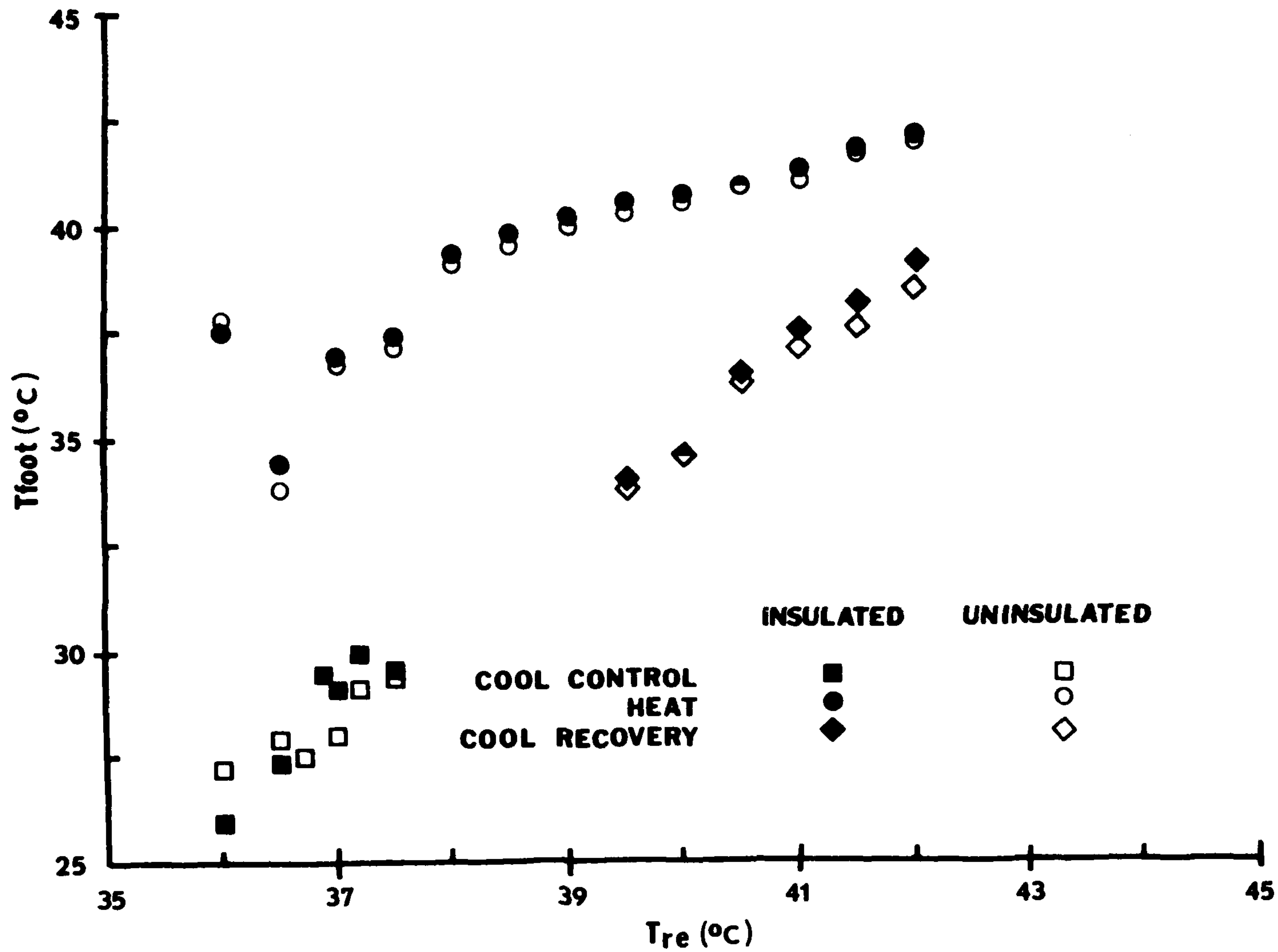

Figure 1c. Skin temperature measured at the foot plotted against rectal temperature during COOL CONTROL, HEAT and COOL RECOVERY.

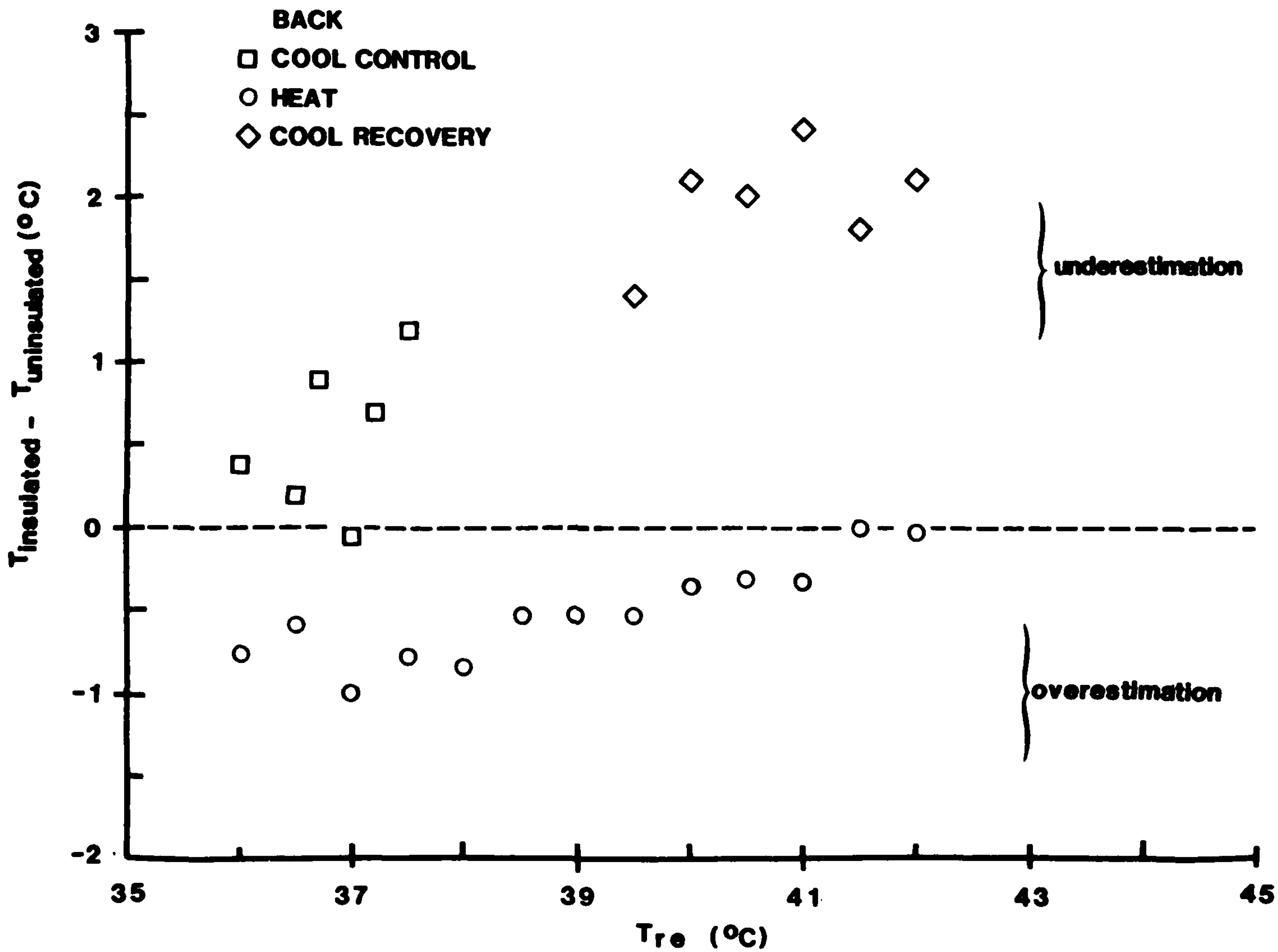

Figure 2a. Difference in temperature measured with the insulated versus uninsulated thermistors at the back during COOL CONTROL, HEAT and COOL RECOVERY.

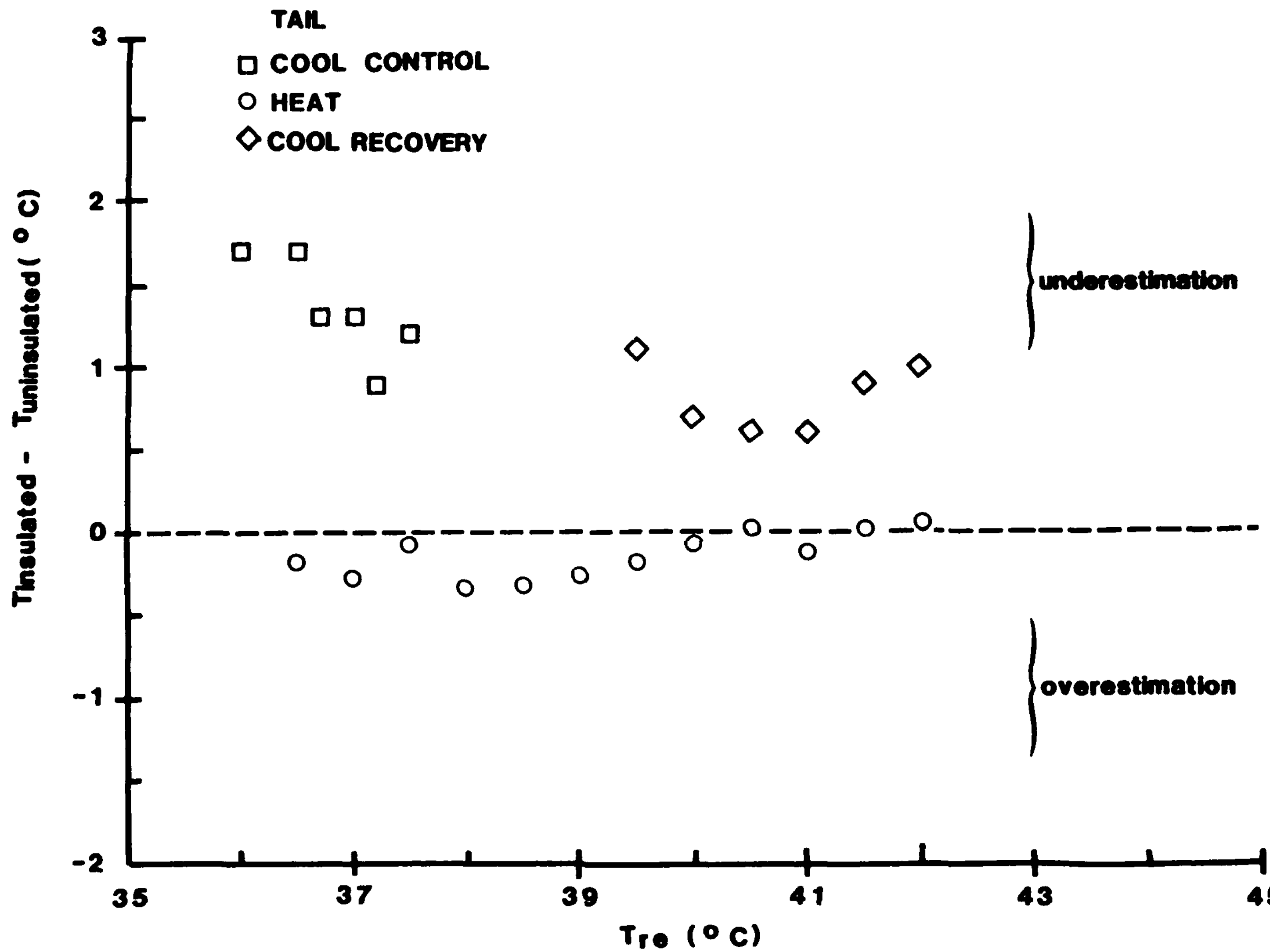

Figure 2b. Difference in temperature measured with the insulated versus uninsulated thermistors at the tail during COOL CONTROL, HEAT and COOL RECOVERY.

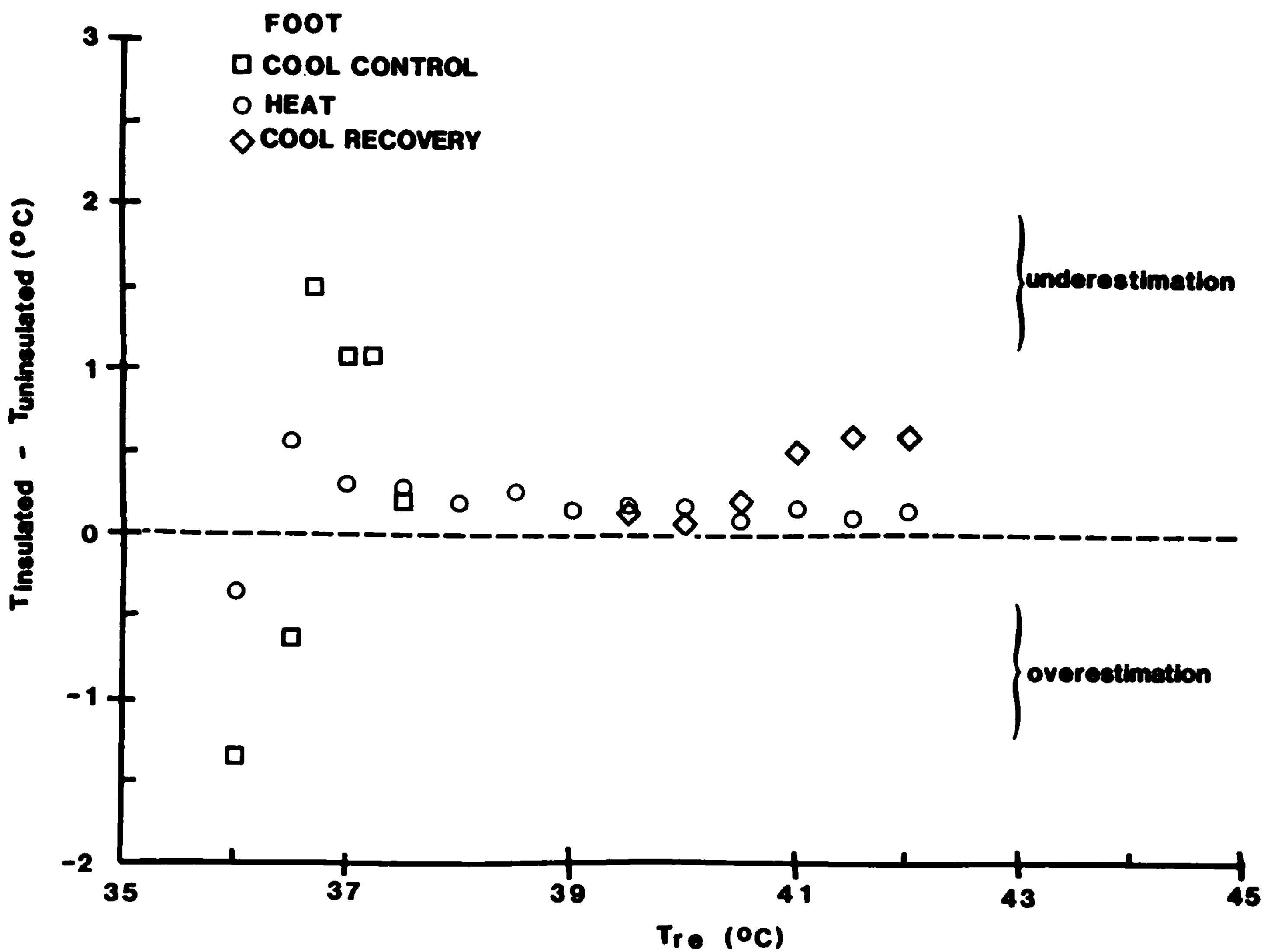

Figure 2c. Difference in temperature measured with the insulated versus uninsulated thermistors at the foot during COOL CONTROL, HEAT and COOL RECOVERY.

Rectal temperature rose from 36.6 $\pm$ 0.2°C at the end of COOL CONTROL to 41.7 $\pm$ 0.2°C at the end of the heating (HEAT) period (Tamb=42°C) in about 54$\pm$4 min. Increases in temperature at all 3 skin sites occurred concurrently with the progressive increase in rectal temperature (Figures 1a, 1b, and 1c). The greatest discrepancy in temperature measured by the insulated and uninsulated thermistors was observed at the midscapular region when rectal temperature was less than 40°C; temperatures obtained with the uninsulated probe were 0.5° to 1.0°C higher ($p<.001$) than those with the insulated probe (Figures 1a and 2a). Similarly, skin temperatures obtained at the dorsal region of the tail ranged form 0.1° to 1.0°C higher ($p<.001$) with the uninsulated thermistor relative to the foam insulated probes (Figures 1b and 2b). In contrast, temperatures measured at the ventral surface of the foot during this HEAT period were consistently 0.1° to 0.6°C higher ($p<.002$) with the insulated than the uninsulated thermistor (Figures 1c and 2c). With rectal temperatures greater than 40°C, the differences in temperature between the insulated and uninsulated thermistors diminished as all 3 skin and rectal temperatures approached the 42°C ambient temperature.

During the 30 min recovery period at 25°C (COOL RECOVERY), rectal temperature fell from 41.7$\pm$ 0.2°C to 39.6$\pm$ 0.2°C. Temperatures measured with the insulated thermistors were significantly higher ($p<.05$) than those recorded with the uninsulated probes (Figures 1a, 1b, and 1c) at all 3 skin sites throughout this range of rectal temperatures. The most striking differences were seen at the midscapular region of the back where temperatures measured with the uninsulated thermistor were 1.4° to 2.4°C ($p<.0001$) lower than those obtained with the insulated probe (Figures 2a, 2b, and 2c). The smallest differences in temperature were recorded at the ventral surface of

the foot, where the insulated probe measured 0.1° to 0.6°C higher ($p<.05$) than the uninsulated probe.

Of particular interest is the observation that the differences between temperature recorded by the insulated and uninsulated thermistors at rectal temperatures of 40.5° to 42°C were greater during COOL RECOVERY than the HEAT period. For example, temperature differences observed for the insulated and uninsulated thermistors (Figures 2a, 2b, and 2c) when rectal temperature was greater than 40°C during the COOL RECOVERY versus HEAT were 2.1±.3°C vs -0.2 ± .1°C for the back, 0.8± 0.2°C vs 0 ± 0.1°C for the tail, and 0.4 ± 0.2°C vs 0.1 ± .0°C for the foot. This suggests that the magnitude of the error can be expected to be proportional to the magnitude of the gradient between skin and ambient temperatures.

The effect of a change in environmental temperature on skin temperature measured with the uninsulated themístor was assessed by comparing the uninsulated and insulated thermistor readings at the transition from COOL CONTROL to HEAT and from HEAT to COOL CONTROL (Table 1). At the transition (first 5 min) from COOL CONTROL to HEAT and again, from HEAT to COOL RECOVERY, the uninsulated thermistors consistently read 0.5° to 2.4°C higher or lower, respectively than the insulated probes.

Discussion

The results of this study indicate that use of an uninsulated thermistor for measuring skin temperature in the rat clearly underestimates skin temperature at cool ambient temperature (about 25°C) and overestimates skin temperatures at high ambient temperature (about 42°C). We recommend using an insulated miniature thermistor to minimize the effects of environmental temperature on the thermistor readings when measuring skin temperature in the rat.

Table 1. Comparison of change in thermistor temperature* with a change in ambient temperature.

	Change in thermistor temperature (^{o}C)	
	COOL CONTROL TO HEAT	HEAT TO COOL RECOVERY
uninsulated back	3.5 ± .7+	-5.4 ± .6+
insulated back	2.5 ± .2	-3.0 ± .3
uninsulated tail	6.8 ± .5+	-5.8 ± .7+
insulated tail	5.4 ± .4	-4.9 ± .8
uninsulated foot	5.6 ± .6	-3.0 ± .3+
insulated foot	5.4 ± .8	-2.5 ± .2

Values are means ± 1SE.

+ significantly greater change than insulated probe, $p < .05$

*change calculated 5 min following transition from COOL CONTROL to HEAT or from HEAT to COOL RECOVERY.

The largest differential in temperature measured between the insulated and uninsulated probes was observed at the cooler ambient temperature (25°C) where the uninsulated thermistor read 0.1° to 2.4°C lower than the insulated probe. During the HEAT period, this large difference in temperature persisted at the midscapular region of the back with the uninsulated probe consistently reading about 0.5° to 1.0°C higher than the insulated thermistor. Rand et al (1965) have shown that in contrast to the marked vasomotor control of the rat's tail, the thermal conductivity and therefore, the cutaneous circulation of fur-covered parts of the rat does not change in response to large changes in environmental temperature. Additionally, since the reflex vasodilation of the rat's tail occurs at ambient temperatures of about 27°-33°C (Rand et al., 1965; Young and Dawson, 1982) the blood vessels in the tail should be maximally dilated during HEAT in the present experiments. Thus, in the present study, one would anticipate that the influence of environmental temperature on thermistor readings located at highly vascular sites would be less than the effect observed at less vascularized and furred areas such as the back. With the predominant vasoconstriction expected during COOL CONTROL, large differences between insulated and uninsulated thermistor readings were seen at both the tail and back skin sites, whereas with increasing rectal temperature and maximal vasodilation of the tail during HEAT, the insulated to uninsulated probe differences in temperature measured at the tail were small compared to those observed at the back.

Estimation of mean skin temperature is instrumental in determining heat storage thermoregulatory mechanisms. Although the laboratory rat is used extensively as a model for human heat injury, no equation exists for estimation of mean skin temperature for this species. Methodology used for

computing mean weighted skin temperature in several animal species (monkey, squirrel monkey, dog) is usually based on the skin sites employed in humans (see Olesen, 1984). Unlike man, these animals have an insulating layer of fur with an adjacent layer of air which would be expected to impede heat dissipation. Since the tail constitutes a significant avenue for heat loss in the rat, the use of the tail as a measure of mean skin temperature (Keilboch et al. 1982) seems inappropriate.

Using an equation similar to that developed by Stitt and Hardy (1971) for estimating skin temperature in the squirrel monkey and the proportion of total surface area that we measured in 540g rats, we compared the estimated mean weighted skin temperature calculated from the insulated and uninsulated thermistors (Table 2). At cool ambient temperature (25°C) during COOL CONTROL and COOL RECOVERY, the calculated mean weighted skin temperature was less with the uninsulated probes than with the insulated thermistors by 1.0° to 1.7°C. Likewise, mean weighted skin temperature was higher using uninsulated rather than insulated thermistors during the HEAT period (42°C). Of particular interest is tail temperature which was markedly less than the calculated mean weighted skin temperature which suggests that tail temperature is an inappropriate index of skin temperature. Future experiments to quantitate skin temperature at multiple sites (10-14) for derivation and assessment of mean skin temperature and heat storage in the rat are planned.

In summary, we insulated a high precision miniature thermistor with a commercially available insulating foam and observed a reduction in the influence of environmental temperature upon the thermistor reading. The skin temperature measurements obtained with the uninsulated thermistor in a cool (25°C) and a hot (42°C) environment were lower and higher, respectively than

Table 2. Comparison of calculated mean weighted skin temperature using insulated and uninsulated thermistors.

condition	Ambient Temperature °C	Rectal Temperature °C	Mean Skin* Temperature °C		Tail Temperature °C	
			I+	UN	I	UN
COOL CONTROL	25	36.5	33.1	32.1	27.1	25.7
		37.5	34.4	32.8	28.5	27.3
HEAT	42	37.5	38.0	38.4	36.1	36.1
		39.5	40.4	40.6	40.25	40.4
		42.0	42.0	42.0	41.8	41.7
COOL RECOVERY	25	42.0	38.8	37.1	37.0	36.0
		39.5	35.3	34.3	32.2	31.2

*mean skin temperature = (Tback *0.68) + (Tfoot * 0.27) + (Ttail * 0.05)

+I = insulated thermistor; UN = uninsulated thermistor

those of its insulated counterpart. Since skin temperature is a component of the heat storage calculation (Hammel et al, 1958), an over- or underestimation of skin temperature would yield an error in the similar direction, in the estimation of heat storage. Use of an insulated thermistor when measuring skin temperatures in furred laboratory animals is recommended.

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